DAMAGE RESISTANCE AND TOLERANCE OF SANDWICH PANELS ñ SCALING EFFECTS

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INTRODUCTION

The damage sustained due to localized accidental loadings has been shown to be a limiting constraint in the design process of a sandwich airframe structure. The use of thin skins with relatively compliant cores makes these sandwich structures vulnerable to impact damage. The low-velocity impact events have been shown [1] to produce very distinct damage states, which are governed by the impactor size. The damage states may vary from clearly visible severe localized skin damage to extensive core damage without any external indications making it difficult to detect [1]. The latter damage states, which are typical of blunt impactors, were found to degrade the residual strength under compressive loading by up to 60% [1].

Even though the previous experimental investigations provide the overall trends associated with the behavior of sandwich panels under impact loads, resulting damage states and residual properties, the observations have been limited to laboratory coupons with idealized boundary conditions. Most previous experimental investigations used coupons of arbitrary planar dimensions, the maximum size being limited by the laboratory test equipment and high cost associated with prototypes. The typical test sections (impact testing) used for sandwich coupons by several investigators are summarized in figure (1). The damage resistance characteristics exhibited by these laboratory coupons may not reflect that of practical airframe structures which are typically several times larger than these coupons. The boundary conditions used in these investigations make the coupons much stiffer in global bending, thereby the local contact stiffness dictating the impact behavior. Thus, the behavior is more representative of laminates/sandwich panels with a substructure (stiffener, frame, etc.) behind (or in the vicinity of) the point of impact and may not adequately describe the behavior of monocoque sandwich structures prevalent in new generation general aviation airframes. Further, it is important to recognize if the damage states existing in the small coupons for a given impact energy range is similar (mode & magnitude) as that which would occur in a larger structure.

Morton [2] investigated the scaling effects on the impact responses for laminated beams using dimensional analysis. The classical scaling laws were shown to apply for elastic behavior of transversely impacted carbon fiber reinforced epoxy beams. The author found that the impact duration scaled as the scale factor and the impact force as the scale factor squared. Swanson [3] reported that the knowledge of the failure mechanisms involved was required to predict the scaling of impact damage. Based on the impact tests on laminated plates and cylinders, the author observed complex scaling behavior of impact damage. Delamination was found to depend on the absolute specimen size whereas the fiber breakage depended only on the applied stresses, independent of the specimen size. Qian et. al. [4] conducted an experimental investigation to determine the

accuracy of scaling rules for impact damage in carbon/epoxy-laminated plates. The results indicated that the overall structural response prior to substantial damage followed the scaling rules quite closely. The formation of damage was found to be more complicated, demonstrating an apparent dependence on scale consistent with fracture mechanics.

The scaling effects on the impact response of sandwich structures have not been well addressed in literature and there is a general lack of experimental data in this area. In an effort to understand and estimate the magnitude of the scaling effects, a limited number of impact experiments are proposed. A finite element based model using experimentally determined contact laws for impact response will be validated and used to simulate the impact tests, using contact laws. A parametric study will then be conducted to evolve a scaling law for impact response and damage resistance of sandwich structures. The scaling effects on the energy dissipation due to local indentation and global vibration will be addressed in particular.
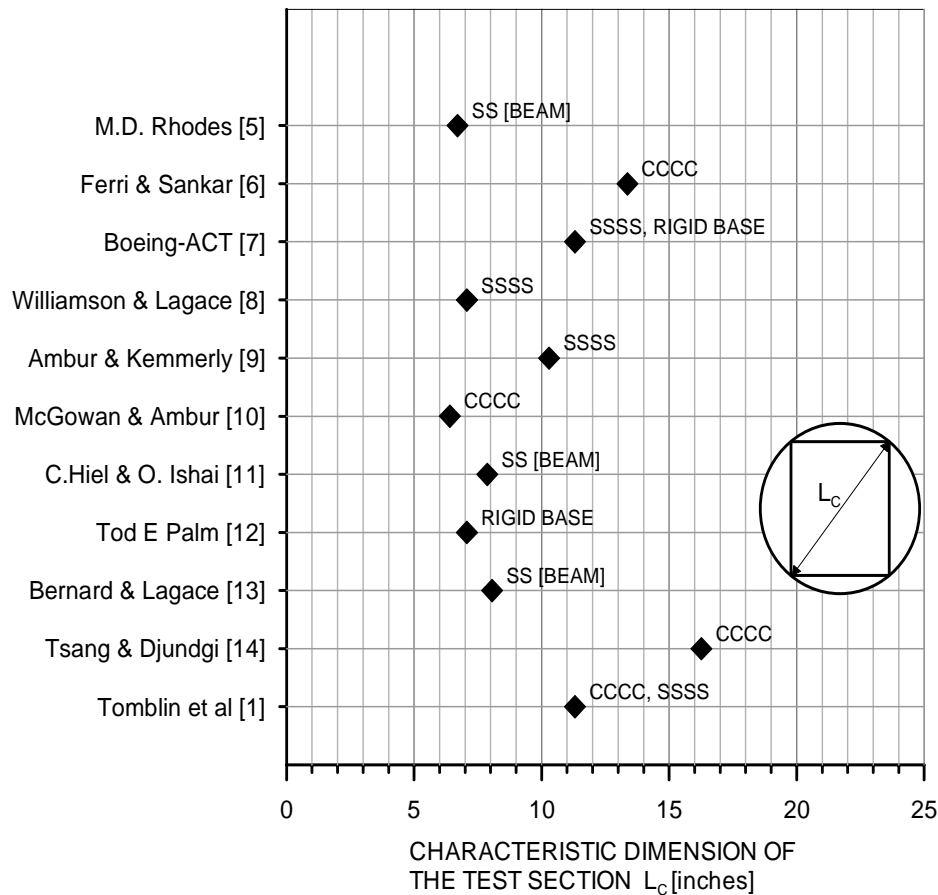

Figure (1): Typical coupon sizes used by different investigators.

TEST PROGRAM

A limited number of impact tests will be conducted on large coupons with different impact energy levels. The impact tests conducted as part of FAA/DOT/AR-00/44 will form a subset of this matrix and thus will serve as baseline data for comparison

purposes. The 3.00″ diameter hemispherical impactor will be used for all the impact tests, as this will facilitate a wider energy range before skin fracture is initiated [1]. The test sections include both square and rectangular regions.

The finite width and height effects on the residual strength behavior of sandwich panels will be investigated for two impact damage states. The impact damages will be inflicted with the 3.00″ diameter impactor with energy levels obtained from previous investigation [1].

MATERIAL SYSTEMS AND SANDWICH CONFIGURATIONS

The sandwich panels will be fabricated using the same material systems reported in [1]. The skins will be fabricated using Newport NB321/3K70P Plain weave carbon fabric prepreg systems. Two different layup schedules, [(90/45)/CORE/(45/90)] and [(90/45)$_2$/CORE/(45/90)$_2$] will be used in this investigation. Plascore® Nomex honeycomb core (PN2-3/16-3.0) of density 3.0 lbf/ft^3 and thickness of 0.75″ will be used as sandwich core.

TEST MATRIX - DAMAGE RESISTANCE

The sandwich panels will be impacted using a drop weight impact tester with a nominal impact velocity of 96.6 in/sec (12″ drop height). The specimens will be impacted at their geometric centers and also at other locations as illustrated in figure (2). Accelerometers will be mounted behind the point of impact to obtain a measure of the indentation depth as a function of time. A total of four energy levels based on previous experience [1] will be used to produce subsurface damage states. The 16″ x 16″ coupons will be impacted at locations other than the geometric center. A total of 28 impact tests will be conducted per sandwich configuration (56 tests overall). The test matrix is summarized in the table below.

Table (1): Test matrix

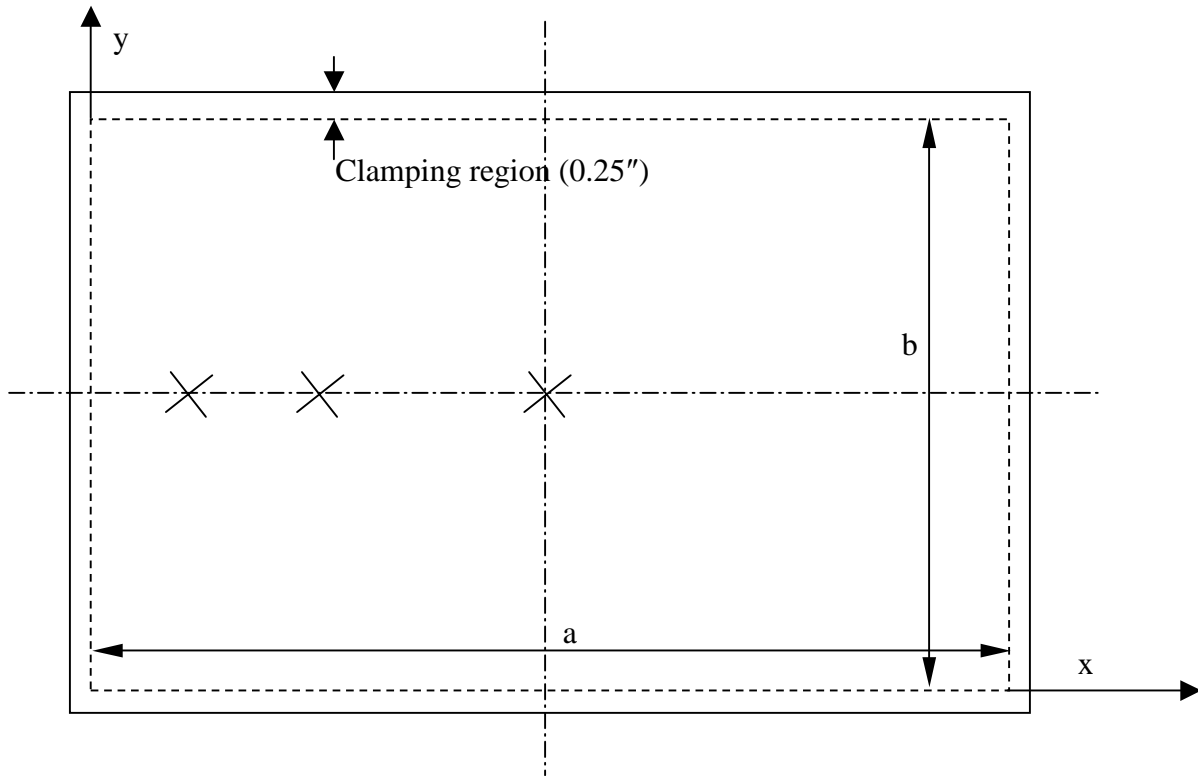| TEST SECTION a × b (inches)		8×8	12×12	16×16	12×24	12×48
BOUNDARY CONDITION		Clamped-RIGID BASE	Clamped	Clamped	Clamped	Clamped
IMPACT LOCATION	(a/2,b/2)	4	4	4	4	4
	(a/4,b/2)			4		
	(a/8,b/2)			4		

Figure (2): Test specimen geometry and impact locations.

TEST MATRIX - DAMAGE TOLERANCE

The sandwich panels will be impacted using a drop weight impact tester with a nominal impact velocity of 96.6 in/sec (12″ drop height). The specimens will be impacted at their geometric centers with suitable impact energies. The boundary conditions and the test sections for impact testing will be the same, irrespective of the overall panel size. The tests will be conducted for both skin types described above. A total of 12 residual strength tests will be conducted and the combinations of height and widths are summarized in table (2). The displacement and strain fields will be recorded using ARAMIS photogrammetric apparatus.

Table (2): Proposed combinations of heights and widths

Test section width ë b í (inches)	6	8	12	16
Test section Height ë H í (inches)	10	10	10	10
			12	
			16	

FINITE ELEMENT MODELING OF IMPACT RESPONSE

The behavior of laminated and sandwich plates subjects to low-velocity impacts has been treated analytically with various degrees of approximations [15]. The behavior of the structure can be modeled to high degree of accuracy using a finite element formulation. The contact between the impactor and the structure can also be incorporated in the model to give an accurate contact load distribution. However, these refined models will require more detailed inputs pertaining to the material properties, boundary conditions, etc., and are further computationally expensive [16].

Another, popular method of studying the impact response is by modeling the local contact phenomenon by a non-linear (dissipative) spring, whose properties are obtained experimentally or by FE modeling [17-21]. This spring is introduced between the impactor and the structure at the point of impact as shown in figure (4). The non-linear contact spring eliminates the contact formulation from the problem. An assumed contact load distribution is used in the analysis. The contact laws generated as part of another program [23], will be used in this investigation. This method can be used as an effective tool for studying the scaling effects associated with the impact response of sandwich plates.

In this study, the effects of different damage states and their magnitudes on the eigenvalues of sandwich panels will be investigated using modal analysis. A finite element model will be used for this purpose. Based on this analysis, the effectiveness of the modeling the contact behavior using a non-linear spring will be appraised. Once, the bounds for the use of this model is set, the FEA impact model will then be used for studying the scaling effects associated with sandwich structures and the results obtained from the experiments described in the previous section will be compared. Using this model, the effects of geometric scaling on the energy dissipated due to local damage formation and global vibration will be analyzed.

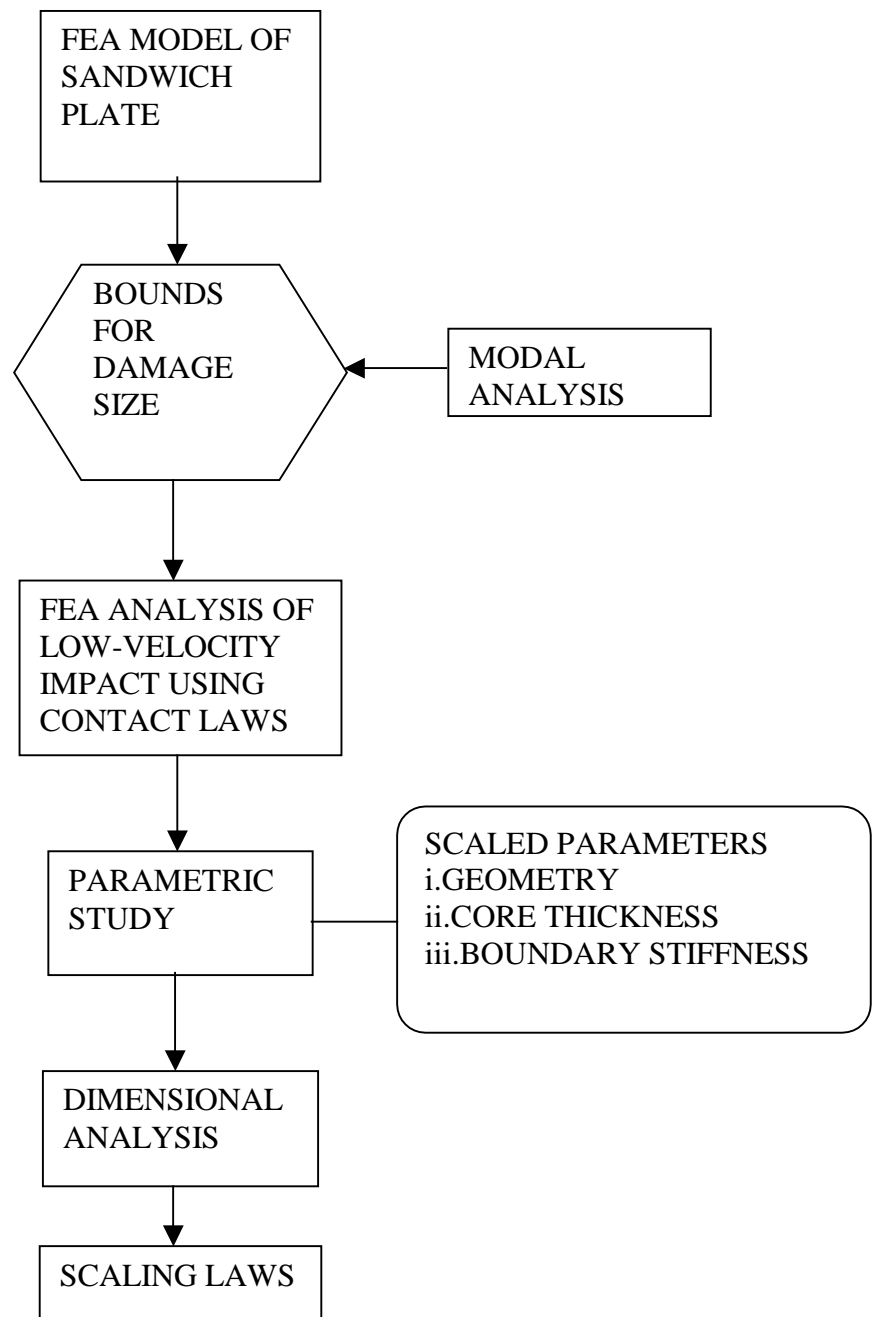Figure (5) depicts an overall flowchart of the proposed program.

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│ FEA MODEL OF    │
│ SANDWICH        │
│ PLATE           │
└─────────────────┘
         │
         ▼
    ╱─────────╲
   ╱ BOUNDS    ╲          ┌─────────────┐
  │  FOR        │◄─────────│ MODAL       │
  │  DAMAGE     │          │ ANALYSIS    │
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┌─────────────────┐
│ FEA ANALYSIS OF │
│ LOW-VELOCITY    │
│ IMPACT USING    │
│ CONTACT LAWS    │
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│ PARAMETRIC  │        │ SCALED PARAMETERS        │
│ STUDY       │────────│ i.GEOMETRY               │
│             │        │ ii.CORE THICKNESS        │
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│ DIMENSIONAL     │
│ ANALYSIS        │
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│ SCALING LAWS    │
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Figure (5). Program overview flowchart.

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